AD-A169 003   SEARCH AND RESCUE MONTE CARLO SIMULATION(U) COAST GUARD   1/1
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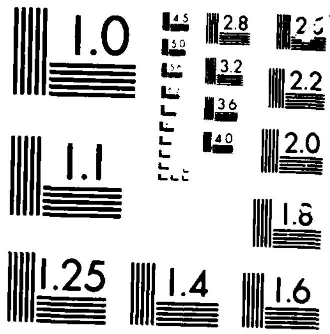

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(2)

Report No. CG-D-12-86

AD-A169 003

SEARCH AND RESCUE MONTE CARLO SIMULATION

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and
S.F. ROEHRIG

U.S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340

FINAL REPORT
MARCH 1985

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Prepared for:

U.S. Department of Transportation
United States Coast Guard
Office of Research and Development
Washington, DC 20593

NOTICE

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-12-86	AD-A169003	

4. Title and Subtitle Search and Rescue Monte Carlo Simulation	5. Report Date March 1985
	6. Performing Organization Code
7. Author(s) C.W. Pritchett and S.F. Roehrig	8. Performing Organiz tion Report No. CGR&DC-4/85
9. Performing Organization Name and Address United States Coast Guard Research and Development Center Avery Point Groton, Connecticut 06340	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Department of Transportation U.S. Coast Guard Office of Research and Development Washington, D.C. 20593	13. Type of Report and Period Covered FINAL REPORT 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This model was developed to evaluate the performance of advanced marine vehicles as well as conventional displacement vessels in Search and Rescue (SAR). It may also be used to investigate the operational and environmental aspects of SAR. Vessel characteristics, environmental and caseload information, including survival limits, are inputs to the model. For the vessel and scenario under consideration, the model produces a point estimate (and confidence interval) of the number of lives saved. A single page output and computer graphic present the information to the user in an easily understood format. The confidence interval can be reduced by making additional runs of this Monte Carlo model.

17. Key Words	18. Distribution Statement
Monte Carlo Search and Rescue Search Theory Measure of Effectiveness	Document is available to the U.S. public through the National Technical Information Service, Springfield,VA 22161

19. Security Classif. (of this report)	20. SECURITY CLASSIF. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

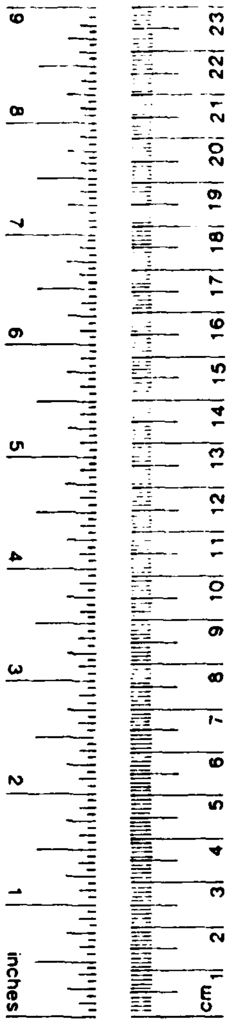
Form DOT F 1700.7 (8/72) **Reproduction of form and completed page is authorized.**

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

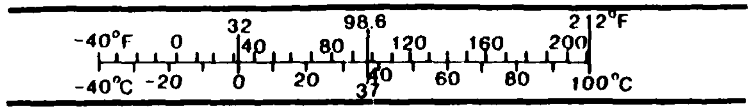
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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NOTATION

CEP	Circular error probable
D	Distance to datum
P	Probability
P_{alive}	Probability of survival
POD	Probability of detection
P_{up}	Probability that ship is up and operational for duration of mission
σ_C	Effect of current on target distribution
σ_W	Effect of wind on target distribution
SS	Sea state
t	Time (general)
t_D	Time from occurence of incident to arrival at datum
t_F	Time to find; i.e., total time spent in search phase
t_S	Total time from incident to arrival on scene
t_T	Total (maximum) search time
t_X	Absolute maximum survival time
t_1	Transit time to datum
t_2	Time to get underway
t_3	Delay time between occurence of incident to CG notification
T_C	24 hour clock time of incident
T_D	24 hour clock time at datum

ADMINISTRATIVE INFORMATION

The Coast Guard Advanced Marine Vehicles (AMV) Project is under the direction of the Marine Vehicle Technology Branch (G-DMT-2) of the Marine Technology Division (G-DMT) in the Office of Research and Development (G-D) in Washington, DC. The AMV Project (9207) consists of three major elements; Operations Research (9207.1), Ship Test and Demonstration (9207.2), and Hydrodynamics (9207.3). The Search and Rescue Model described in this report is part of the Operations Research element. It was developed by the Marine Systems Branch of the Coast Guard Research and Development Center in Groton, Connecticut. The Research and Development Center is a Headquarters Unit reporting to the Chief of the Office of Research and Development (G-D).

INTRODUCTION

The U.S. Coast Guard is in the process of evaluating Advanced Marine Vehicles, such as hydrofoils, planing boats, Small Waterplane Area Twin Hulls (SWATH) and surface effect ships, as potential Coast Guard cutters. A necessary part of this process is to quantify the operational performance of AMV's and conventional displacement craft in Coast Guard missions so comparisons can be made between, and among, these different types of vessels. Quantifying performance is only part of the problem. To take advantage of their unique characteristics, AMV's may be operated differently than conventional cutters. It is also necessary to understand how these different methods of operation may affect the operational performance.

An accepted method of addressing these concerns is by the use of a model. To be useful, a model must be flexible and still address the technical issues of the problem. In the case of Search and Rescue (SAR), the model must be able to address the salient aspects of a typical case such as distance to datum, search, survival time, and weather, but more importantly, the model must produce outputs that relate directly to the goal of the SAR program (saving lives). Furthermore, the outputs should be quantifiable and verifiable in practice. The goal of this model of SAR is to be able to quantify the lifesaving performance of various AMV concepts and understand how their unique characteristics influence mission performance. The rationale for quantifying SAR performance for a vessel is presented in Reference 1.

Several requirements were placed upon the development of the SAR Model. They were:

1. be supportable with available or measurable data,
2. be capable of distinguishing between craft types, and
3. be able to accurately reflect important mission factors.

The philosophy was to model the vessel and operation at as high (macro) a level as possible and still satisfy the requirements.

At this point, it is important to consider a fundamental assumption of the model, that is, life-threatening SAR cases deteriorate with time. If the mariner is in need of assistance, the situation will not improve on its own. The boat will eventually sink, he or she will become exhausted and hypothermia will set in. At some time, the maximum survival time, t_x, the mariner will no longer survive. We model the probability that the mariner is alive with a monotonically decreasing function of time which becomes zero at t_x. This curve is called the survival function. The smaller the value of t_x, the more critical time is in the SAR case. It follows that if t_x is very large, then time is not critical in the case.

Although this concept of a survival function is logically consistent, it generates a problem that cannot be ignored. That is, it is very difficult to accurately define the curve. It is also difficult to distinguish between the capabilities of vessels when the cases are not sensitive to time. Moderate or low severity SAR cases typically exhibit this type of behavior. An attempt by Arrigan (Reference 2) to determine survival curves for life-threatening (high severity) cases from the Coast Guard SAR data base was thwarted by the lack of

reported information and the limited number of cases with the same set of controlled conditions. For an initial approximation, the hypothermia curve from the National SAR Manual (CG-308) can be used to define the survival curve. This is only applicable for people-in-the-water cases. Furthermore, temperature is restricted to only one of two values (over or under 60°F). Relative comparisons of vessels will be sensitive to the survival function. Even though the shape of the curve and maximum survival time are not accurately known, we can still use the concept and vary the value of t_x as a model parameter. With successive runs of the model, the user can determine a relative measure of SAR effectiveness for the vessels of interest.

The original model of SAR used multiple convolutions to arrive at a solution. The approach presented here uses a combination of discrete and continuous distributions to represent the variables in a SAR case. This required the use of Monte Carlo techniques to draw samples from the distributions since multiple convolution of the mixed probability densities appeared intractable. However, the entire model is of such a size that thousands of replications can be run at minimal cost. The problem of data availability is attacked essentially by breaking down the critical variables into more elemental (and thus more easily estimatable) factors. For instance, search time is the result of datum uncertainty, craft search capability (search width and search speed), and drift factors affecting the original datum. Mathematical search theory is then used to recombine these variables to yield the distribution of search times.

SAR MODEL

Assumptions

Before proceeding to a description of the SAR model, it should be emphasized that the function of the model is not to do a complete analysis of the SAR mission. Its purpose is only to compare, in a relative sense, the lifesaving capability of different craft under the same set of conditions. This comparison is based on the distribution of the relevant factors of a SAR case, such as sea state and the distance to the reported datum, and vessel characteristics such as speed in seaway, sensor sweep width, and reliability. It was necessary to make certain assumptions to make the model results more useful. Specifically:

1. Saving a life is the primary goal in SAR, salvaging property is secondary. If a vessel is a good lifesaver it is assumed to be a good property salvor.

2. Structural details of specific craft types are not modeled. The lifesaving function can be performed equally well from any vessel.

3. Design will account for all appropriate safety aspects. Good seamanship is assumed.

Specific design requirements can be built into any of the AMV concepts. For example, if low speed maneuverability is a requirement, an out-drive can be installed on any type of vessel. If low freeboard or a specific height of

eye are required in SAR, they can be incorporated in the design of the vessel. The fundamental difference in vessel types for purposes of the model is the maximum speed of the vessel and the speed it makes in a seaway.

With this background, the computational flow of the model can be traced (Figure 1a and 1b). For consistency, boxes with double borders are used for distributions of variables which are drawn at random, calculations and other deterministic relationships are in single-bordered boxes, and data passed from one model section to another are in circles.

Starting at the top left of Figure 1a, a sea state, SS, is drawn from the distribution of sea states and passed to the box to the right containing the vessel speed-sea state characteristic curve of L. The speed in the seaway, V, is then calculated. After drawing a distance to datum, D, for the SAR case, the speed, V, and distance, D, are combined to produce a sample transit time to datum, t_1. Samples are then drawn from the three remaining distributions on the left of Figure 1a, i.e., Time to get Underway, Incident to Notification Delay, and Incident Time of Day. The 24-hour clock time, T_D, is then computed as well as the elapsed time, t_D, from the inception of the case until the vessel arrives at the datum.

The probability of survival versus the time (from incident) curve is in the upper right of Figure 1a. This curve is chosen, as are all the probabilities in the model, to reflect the class of scenarios being considered. The time t_x is an estimate of the maximum survival time, given the environmental conditions and the type of incidents being investigated (e.g., persons in life raft, in the water, etc.). The search time is computed by assuming that the search will be terminated at the next sunset after the maximum survival time has elapsed (given that the search has been unsuccessful to that point). There are certainly remarkable cases on record where people have survived for extended periods of time "against all odds," but it is equally true that every unsuccessful search is stopped at some point. The rule used here to stop the search was chosen as a reasonable one, and is consistent with the overall goal of the model, that is, to fairly compare various craft in SAR.

The next step in the model is to prepare a probability of detection curve extending up to the time the search is terminated. The results of Koopman (Reference 3) on optimal search of bivariate (two variables) normal target distributions are used, along with a splicing technique to account for sequential changes in search capability in daylight and darkness. An initial estimate of target location is quantified in terms of the model input CEP ("circular error probable", or the radius of the smallest circle with a 50% chance of including the actual target location). This circular distribution is modified by the drift effects of current and wind (labeled σ_C and σ_W in the lower left corner of Figure 1b) to produce an expanding target distribution. The details of these calculations are given in Appendix A. The craft's search capabilities are input in terms of search speed and search width for the two different regimes (day/night). All of this information is mathematically combined to produce probability of detection (POD) curves for day and night. These curves, in conjunction with the data on sunrise and sunset times, the time of search initiation and maximum search time, yield a composite cumulative probability of detection curve ("cumulative" box, Figure 1b) for the case being evaluated. The time at which the search will be terminated is labeled T_T.

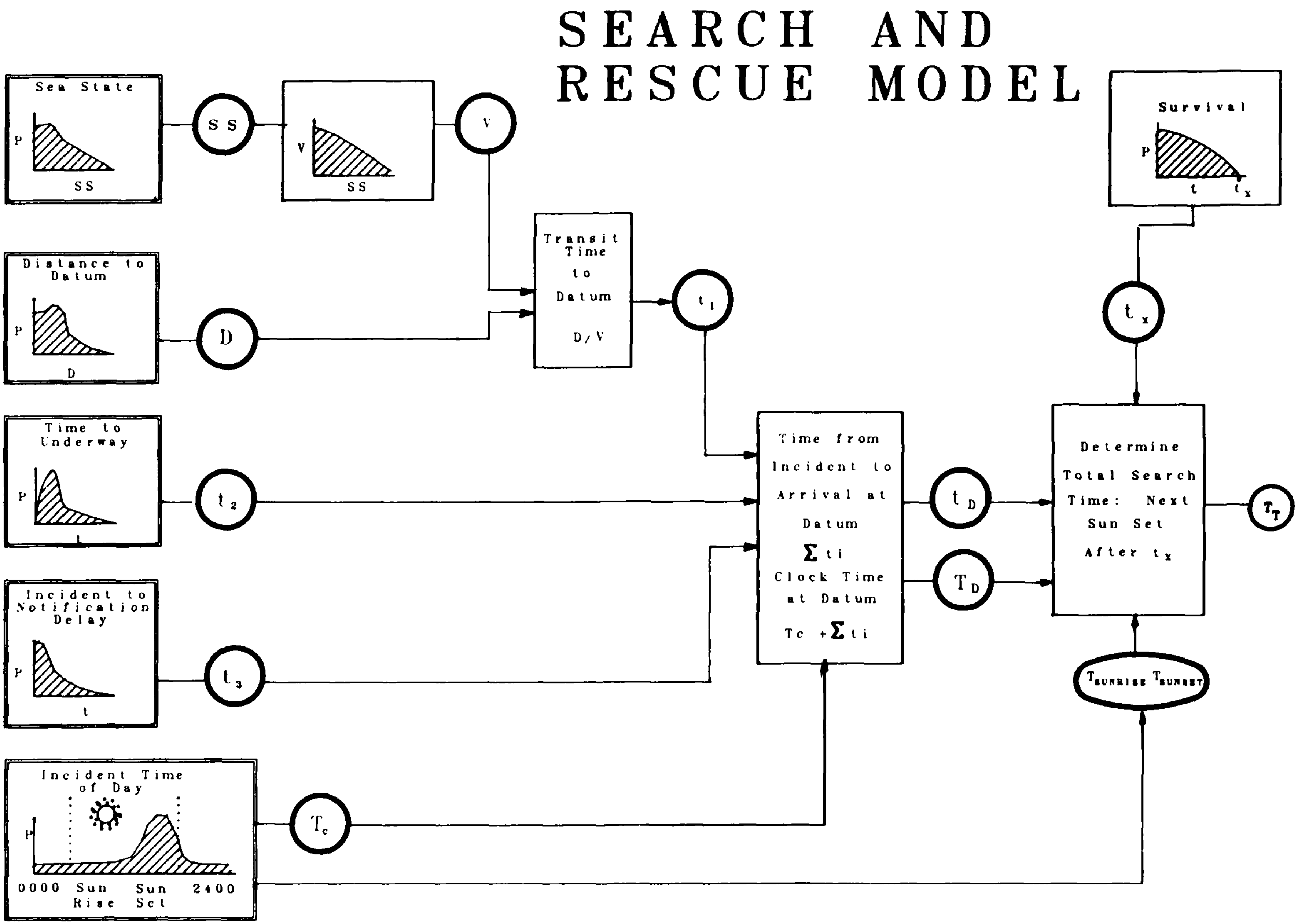

SEARCH AND RESCUE MODEL
Sea State
P
SS
S S
V
SS
V
Distance to Datum
P
D
D
Transit Time to Datum
D/V
t_1
Time to Underway
P
t
t_2
Incident to Notification Delay
P
t
t_3
Incident Time of Day
P
0000 Sun Rise Sun Set 2400
T_c
Time from Incident to Arrival at Datum
Σt_i
Clock Time at Datum
$T_c + \Sigma t_i$
t_D
T_D
Survival
P
t
t_x
t_x
Determine Total Search Time: Next Sun Set After t_x
$T_{SUNRISE}$ T_{SUNSET}
T_T

FIGURE 1a

SEARCH AND RESCUE MODEL

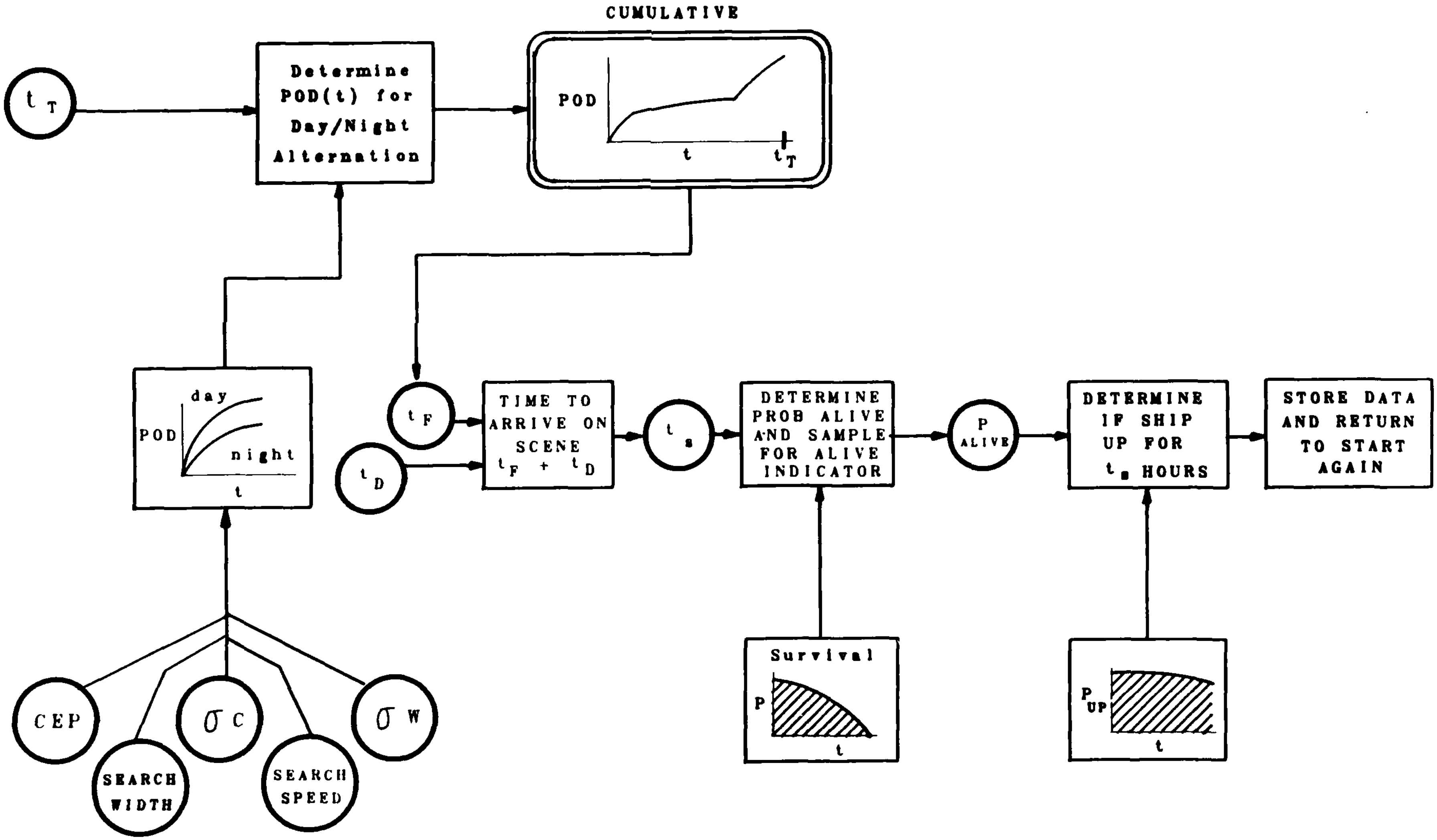


FIGURE 1b

To generate a sample time to detection, a number is drawn at random from the interval [0, 1.0]. If this number is larger than the POD at maximum search time, then it is assumed that the search is terminated unsuccessfully. Otherwise, the inverse POD function is evaluated, producing the sample time to find.

The time to arrive on scene, t_S, is computed by adding the time to datum, t_D, to the time to find t_F. The probability of survival is determined by entering the survival curve and reading off the ordinate value associated with t_S.

Finally, a random draw is made from the craft's reliability curve to see if it is operational for the time required to effect the rescue. This information is not presently used to affect the results of a case. No delays for repair are yet included in the model. Only a 1/0 indicator (vessel up or down for t_S hours of operation) is logged. The various times and probabilities for this replication are then stored in memory for future post-processing, and the entire procedure is begun again.

Computer Program

A FORTRAN program has been written and tested to implement the SAR model. A listing is included in Appendix C. It is presently running on a Digital Equipment Corporation VAX 11/780 located at the Naval Underwater Systems Center in New London, Connecticut. In operation, the user is prompted to select from a variety of available distributions to reflect the scenario and operating capabilities under investigation. In addition, the user has the option of generating new distributions if it is felt that those provided are unsuitable. Such inputs as wind, current, search widths, and sunrise and sunset times are completely user determined. A text file containing general information and operating instructions is available in the same user area. Since the computer is located at a secure naval facility, access is restricted to authorized personnel. Individuals wishing to run the program should contact the Marine Systems Branch at the Research and Development Center for specific access procedures.

Post Processing

The basic procedure in the data reduction of the outputs of Monte Carlo models consists in first determining a quantity to be estimated (e.g., search time, total time to scene, fraction of lives saved), averaging it over some number (n) of samples, and statistically determining a confidence interval containing the average value. Distributions of outputs are assumed to be asymptotically normal. Therefore, the confidence interval is inversely proportional to the square root of the sample size. If the confidence interval is too large, additional samples can be run. Since there is a relationship ($1/\sqrt{n}$) between the size of a confidence interval and the number of samples, an estimate can be made of the number of additional samples necessary to yield a confidence interval of the desired size. The model can be run again for the newly computed sample size to produce a new point estimate and confidence interval.

A program to perform the statistical processing on fraction of lives saved is currently available in the same file space in which the model resides.

Details of its operation and user information for the SAR model can be found in the accompanying text file.

Output Format

The model was developed to compare different craft in various operational scenarios. Two basic styles of one-page reports were designed to convey the results as concisely as possible. Figure 2 is an example of the first of these, and should be self-explanatory, given the preceding discussion. The mission performance section gives the bottom line, that is the overall fraction of lives saved. The remainder of cases are broken out into the fraction of those cases where the search resulted in finding the subject expired, and that fraction where the search itself was unsuccessful in locating the mariner. The overall results then sum to 1.0. The 95% confidence interval is that obtained by the usual t-statistic, i.e., the model output is considered normally distributed about the mean value of fraction of lives saved.

The second output is the graphical layout of Figure 3. The central body of the graphic depicts the scenario, highlighting the craft capabilities on the left and the elliptical search area on the right. The larger rectangle and the inset cross-hatched rectangle show day and night search speeds (horizontal dimension) and sensor search widths (vertical dimension). The product of speed and sweep width is the correct measure of search capability, and the areas of the rectangles show this. The average distance to datum and the average time to datum are near the bottom of the graphic. The elliptical region depicts the minimum area with a 50% chance of containing the target (elliptical equivalent of CEP) and its area is noted. The cross is annotated with the maximum survival time.

Across the top of the graphic are:

1. Specific information on the craft, including speed and range capabilities.

2. A clock showing times of light and darkness (night is cross-hatched) along with two radial lines representing quartiles of the time of day of incident distribution (in this example, between approximately 1300 and 1700 hours 50% of the cases occur). The time of the peak caseload is indicated by the arrow.

3. A wide panel giving indicators of the environment: water temperature, sea conditions (quantified by the percentage of waves larger than three feet), and the wind and current. The absolute headings of wind and current are not important since the size and shape of the target uncertainty region are affected only by the relative angle between them. (This angle is depicted in the graphic.)

4. The performance of the craft in terms of fraction of lives saved, along with a similar bar graph for a user selected baseline craft. The bar on the left represents the fraction of SAR cases with a successful outcome (i.e., life saved), the bar on the right represents that fraction where the search found the subject after death occurred, while the gap between the two bars

EXAMPLE OF R&DC SAR MODEL SUMMARY OUTPUT*

** SAR VESSEL

TYPE: BOEING PHM VARIANT

MAX SPEED IN CALM WATER	48.0	KTS
MAX SPEED IN SEA STATE 3	42.0	KTS
AVG TIME TO GET UNDERWAY	0.10	HRS
AVG TIME TO INCAPACITATING FAILURE	650.0	HRS
DAYTIME SEARCH SWEEP WIDTH	30.0	NMI
NIGHTIME SEARCH SWEEP WIDTH	10.0	NMI

** CONCEPT OF OPERATIONS

SEARCH UNTIL NEXT SUNSET AFTER MAXIMUM SURVIVAL TIME.
OPTIMAL SEARCH OF TWO-DIMENSIONAL NORMAL TARGET DISTRIBUTION.
SEARCH SPEEDS:

DAYTIME	38.0	KTS
NIGHTIME	12.0	KTS

** SCENARIO

ONE SAR CASE AT A TIME; NO MULTI-UNIT SEARCH OR PRIORITY DIVERSIONS.

* CASELOAD:		
AVG DELAY BETWEEN INCIDENT AND CG NOTIFICATION	0.13	HRS
TIME OF PEAK CASELOAD	1500	HRS
ABSOLUTE MAXIMUM SURVIVAL TIME	6.2	HRS
* OPERATING AREA:		
AVG DISTANCE TO DATUM	65.0	NMI
DATUM UNCERTAINTY (50% CEP)	17.6	NMI
CURRENT	3.5	KTS
WIND	15.0	KTS
RELATIVE ANGLE BETWEEN CURRENT AND WIND	110	DEG
FRACTION OF WAVES GREATER THAN 3 FEET	0.22	
SUNRISE	0500	HRS
SUNSET	1900	HRS

** RESULTS

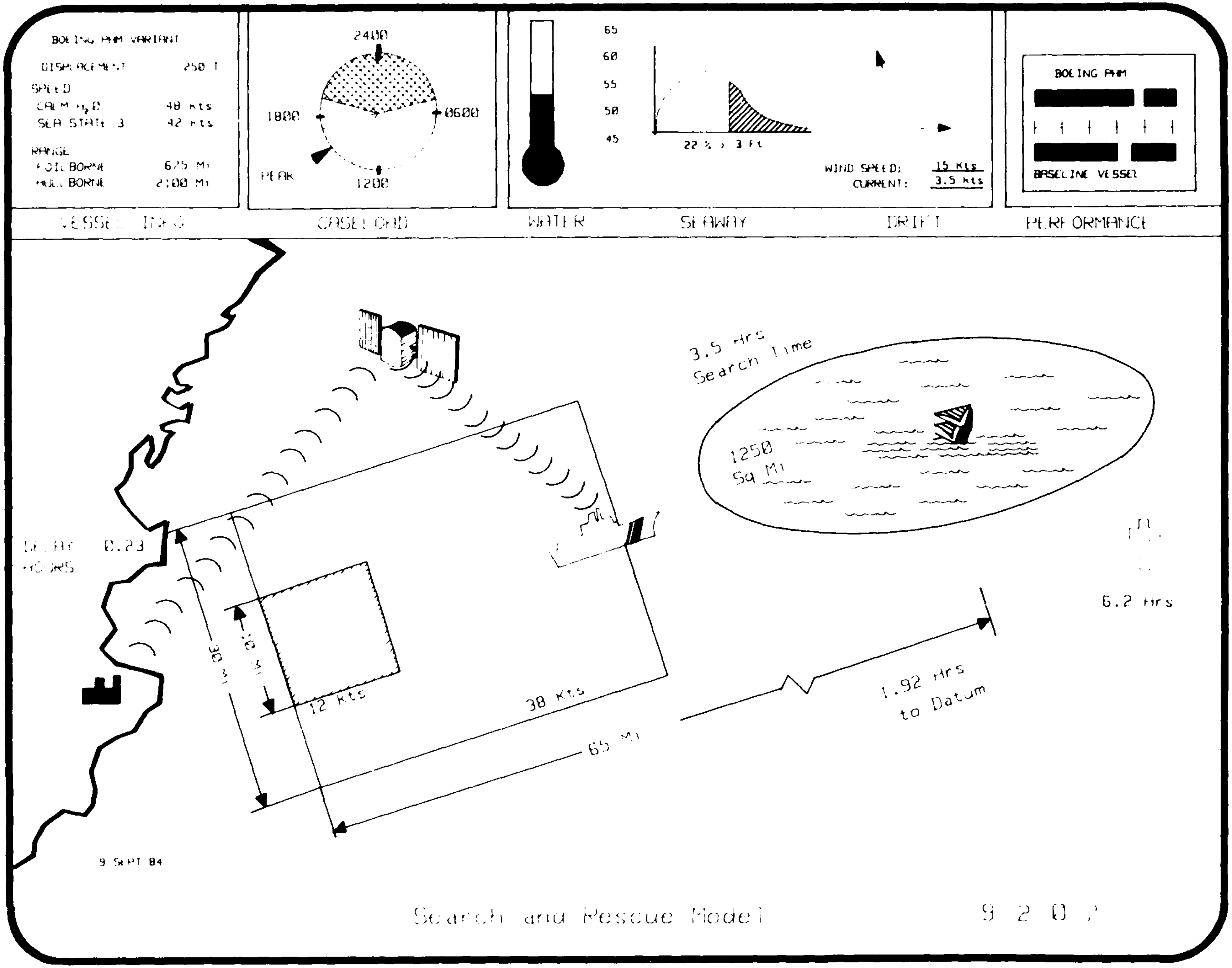
* OPERATIONAL PERFORMANCE		
AVG TIME TO DATUM	1.92	HRS
SEARCH AREA (50% CEP) UPON ARRIVAL AT DATUM	1250	SQMI
AVG SEARCH TIME	3.50	HRS

* MISSION PERFORMANCE	ALIVE	DEAD
FRACTION FOUND BEFORE SURVIVAL LIMITS	0.73	0.04
FRACTION FOUND AFTER SURVIVAL LIMITS		0.16
FRACTION NOT FOUND (PRESUMED DEAD)		0.07
OVERALL	0.73	0.27

* STATISTICS	
95% CONFIDENCE INTERVAL AROUND FRACTION ALIVE	(0.70, 0.76)
NUMBER OF MONTE CARLO SAMPLES	1000

*Representative; not actual model outputs

FIGURE 2



BOEING PHM VARIANT
DISPLACEMENT 250 T
SPEED
CALM H_2O 48 Kts
SEA STATE 3 42 Kts
RANGE
FOILBORNE 675 Mi
HULLBORNE 2100 Mi
2400
1800
0600
1200
PEAK
65
60
55
50
45
22 % > 3 Ft
WIND SPEED: 15 Kts
CURRENT: 3.5 Kts
BOEING PHM
BASELINE VESSEL
VESSEL INFO
CASELOAD
WATER
SEAWAY
DRIFT
PERFORMANCE
DELAY 0.23 HOURS
3.5 Hrs Search Time
1250 Sq Mi
6.2 Hrs
30 Mi
10 Mi
12 Kts
38 Kts
65 Mi
1.92 Hrs to Datum
9 SEPT 84
Search and Rescue Model

indicates the remaining fraction of cases where the search was unsuccessful (presumed dead). The entire scale thus has length 1.0.

Both output formats try to compress into a single sheet a great deal of information. The actual inputs to the model are in large part distributions. Thus an attempt has been made to use either one or two numerical quantities, usually average values, or a graphical representation to summarize these distributions.

EXAMPLE RUNS

The outputs of the SAR model depend upon the distributions that make up the model. When representative and realistic distributions can be obtained, the model can be used constructively. The model will be useful certainly for it's intended purpose, that is to compare the effectiveness in SAR of various ship designs. It may also be useful in determining the effect of various ship design characteristics upon SAR performance. Although the model was not designed to explore the operational aspects of SAR, it may be useful in determining how parameters such as distance, notification time, and darkness affect operational performance.

An example of how the model might be used to see the effect of the seaway upon six vessels' SAR performance follows. Remember, although there are not many variables in the model, a large number of runs may be required (combinatorial explosion) since the number of values for each parameter are multiplied to give the total number of runs.

The distributions shown in Figure 4 were chosen. The incident times were spread uniformly over the 24-hour day, sunrise was at 0600 and sunset at 1800 hours. Appendix B provides an explanation of the technique used to parameterize the wave height distributions. The six vessels and the associated speed-wave height relationships are presented in Table 1. Each model run consisted of 2000 replications, i.e, individual SAR sorties. The model outputs are presented in Figure 5. It can be seen that as the seaway increases, the fraction of lives saved decreases with all of the vessels. The higher values for the hydrofoil can be attributed to its high speed, both in calm water and in a seaway. This follows since we are considering only life-threatening cases as reflected by the survival curve (Figure 4).

It is interesting to note that the fraction of lives saved and the speed-sea state relationship correlate very positively for the six vessels. The correlation coefficients are presented in Table 2. Many people have had this insight into SAR performance for a long time. What makes the model useful is to be able to quantify results and make the correlations to see if there is a relationship between variables. This can help one to understand more fully the relationship between vessel characteristics and mission performance. Operational choices, such as speed to search, and sensors extending sweepwidth, may also be analyzed using the model.

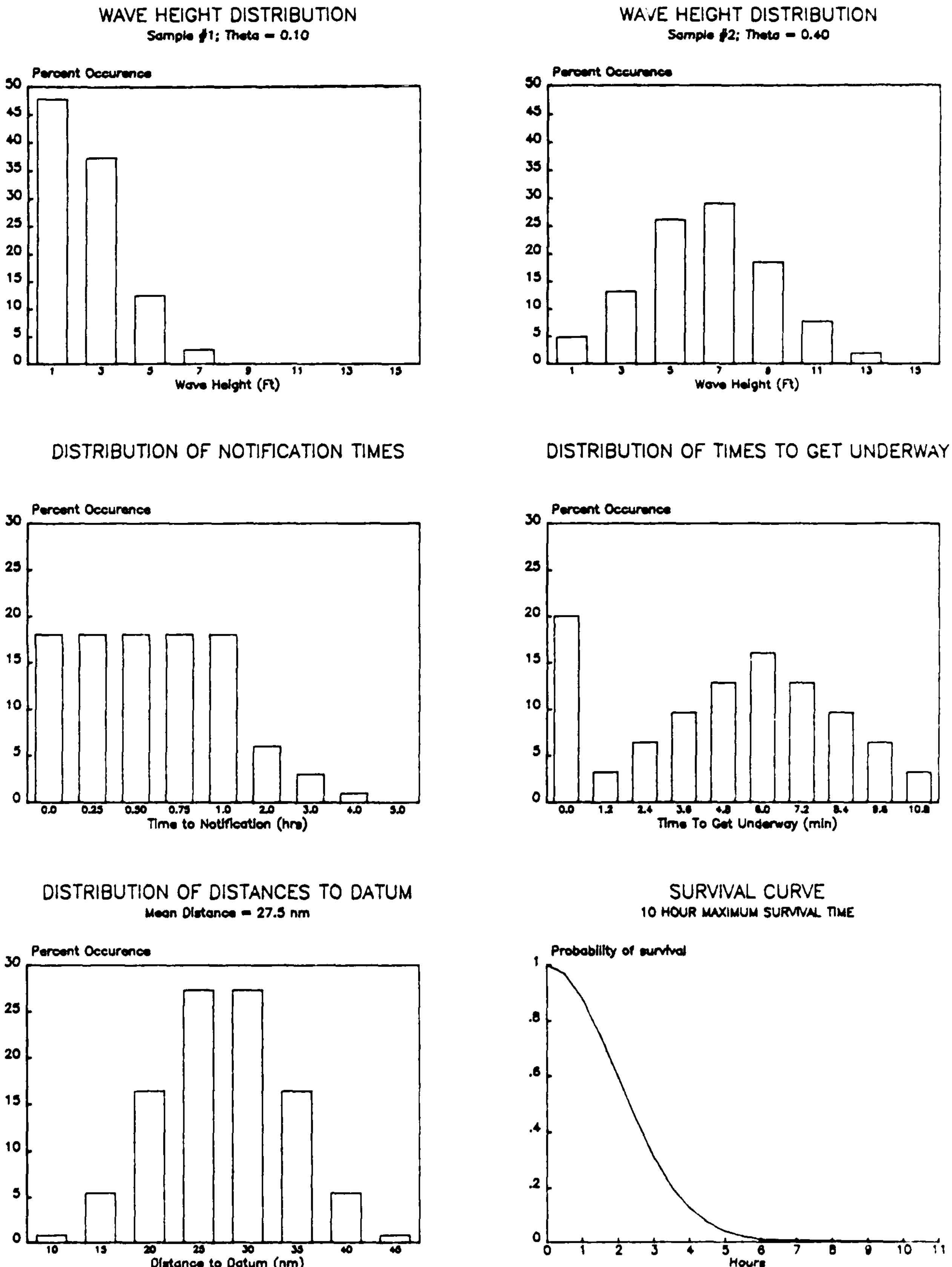

WAVE HEIGHT DISTRIBUTION
Sample #1; Theta = 0.10
Percent Occurence
Wave Height (Ft)
WAVE HEIGHT DISTRIBUTION
Sample #2; Theta = 0.40
Percent Occurence
Wave Height (Ft)
DISTRIBUTION OF NOTIFICATION TIMES
Percent Occurence
Time to Notification (hrs)
DISTRIBUTION OF TIMES TO GET UNDERWAY
Percent Occurence
Time To Get Underway (min)
DISTRIBUTION OF DISTANCES TO DATUM
Mean Distance = 27.5 nm
Percent Occurence
Distance to Datum (nm)
SURVIVAL CURVE
10 HOUR MAXIMUM SURVIVAL TIME
Probability of survival
Hours

FIGURE 4

TABLE 1

VESSELS AND SPEED-WAVE HEIGHT RELATIONSHIPS

Wave Height	Hydrofoil	Planing Hull	SWATH	SES	Displacement	95-Footer
1.0 ft	34.4	31.6	27.6	30.8	26.8	24.0
3.0	33.3	25.8	27.6	27.2	21.9	22.5
5.0	32.3	21.3	27.3	24.7	18.1	19.0
7.0	31.4	18.0	26.8	22.7	15.2	17.0
9.0	30.6	15.9	25.9	21.1	13.5	13.0
11.0	29.8	15.1	24.8	19.4	12.8	12.0
13.0	5.0	0.1*	23.4	17.4	9.0	12.0
15.0	5.0	0.1*	21.7	14.7	7.0	12.0

* Vessel essentially dead in water; non-zero values prevent divide by zero errors. Entries in knots.

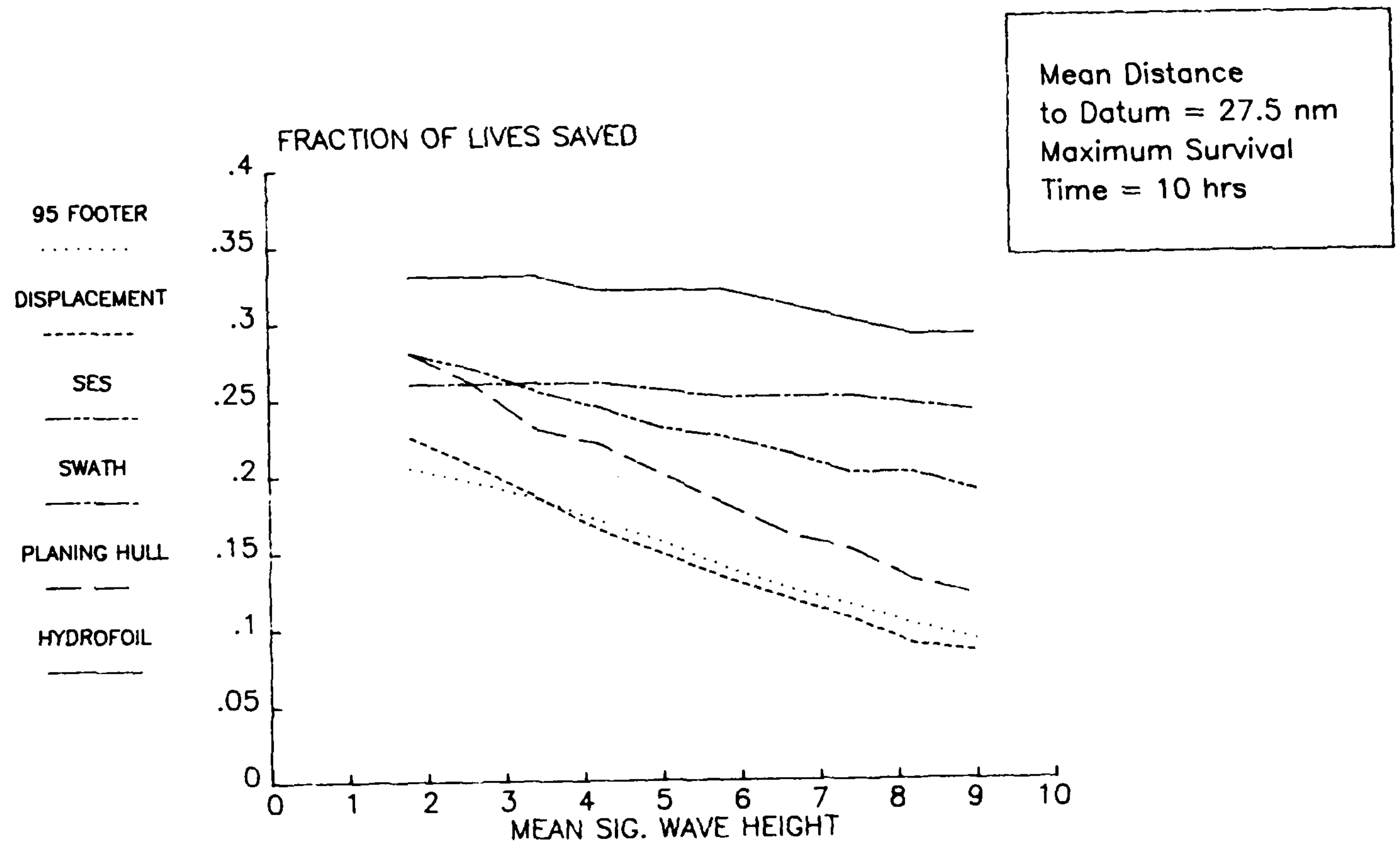


FIGURE 5 - Example of SAR Program Results

TABLE 2

CORRELATION FRACTION (LIVES SAVED AND SPEED-SEA STATE)

Ship Type	Correlation Coefficient
Hydrofoil	0.965
Planing Hull	0.979
SWATH	0.988
SES	0.998
Displacement	0.997
95-Footer	0.993

The model results can be used to compare the SAR performance of various AMV and conventional vessels. An agreed upon set of conditions, or range of values, would be entered into the model and a series of runs would be made. The ultimate rank ordering of different vessels requires an accepted Measure of Effectiveness (MOE) and evaluation procedure. For example, the MOE might very well be the fraction of lives saved, but this might be combined with an MOE from non life threatening cases such as time to arrive on scene. Any evaluation requires one to completely and carefully spell out the procedure. This model can be very useful in that process.

REFERENCES

1. Tedeschi, Louis C., "Development of Measures of Effectiveness for Marine Vehicles for Coast Guard Missions," USCG Report # CG-D-8-82.

2. Arrigan, John, "SAR Measures of Effectiveness for Advanced Marine Vehicles," USCG Report # CG-D-02-82.

3. Koopman, Bernard O., Search and Screening, New York, Pergamon Press, 1980.

GLOSSARY

Datum: The most probable location of the search object corrected for drift at any particular moment during the mission.

Distribution: A quantitative description of the relative likelihoods of various possible outcomes of an experiment.

Monte Carlo Simulation: A probabilistic model of a system whose solution is obtained by repeated sampling from appropriate distributions, rather than by closed form manipulation. As in any simulation, results are specified by statistical estimates.

Probability of Detection (POD): A mathematical function which reflects the odds of success or failure in detecting the search target, under the assumptions of a given search pattern, sensor search capabilities, etc. POD is always between 0 and 1, e.g., a POD of 0.5 implies a 50-50 chance of detecting the target.

APPENDIX A

In this appendix, the method used to predict the expansion of the target uncertainty region is presented. Referring to Figure A-1, point P_1 is the original datum and S_E is the original CEP. An empirical result developed by the Oceanography Branch, USCG R&D Center, gives R, the new CEP around new datum P_2, after drifting a distance D as:

$$R = 1.1 \sqrt{.3\ D^2 + S_E^2 + S_V^2}$$

where S_V is the self-localization accuracy of the vessel trying to get to datum.

From information in the National Search and Rescue Manual, it was determined that the important contributions to the drift distance D are:

1. Leeway, taken to be in the direction of the wind,
2. Wind current drift, also taken to be in the direction of wind, and
3. Sea current drift, in the direction of current.

Referring to Figure A-2, an application of the law of cosines gives

$$(DS)^2 = (CD)^2 + (L+WD)^2 - 2(CD)(L+WD) \cos(\pi - \theta)$$

where
- L = leeway speed
- CD = sea current drift speed
- WD = wind-driven current drift speed
- θ = angle between wind and current
- DS = drift speed

Then $D = DS \bullet T$ where T is the drift time

The following representative numbers were taken from the National Search and Rescue Manual:

L = (0.05)(wind speed)

WD = (.033)(wind speed) - 0.23
or (whichever is larger)
0.0

CD = current speed

These values have been hard-coded into the SAR model, but are easily changed if it is deemed necessary.

Example: wind speed = 30 kts
current = 2 kts
$\theta = 60^\circ$

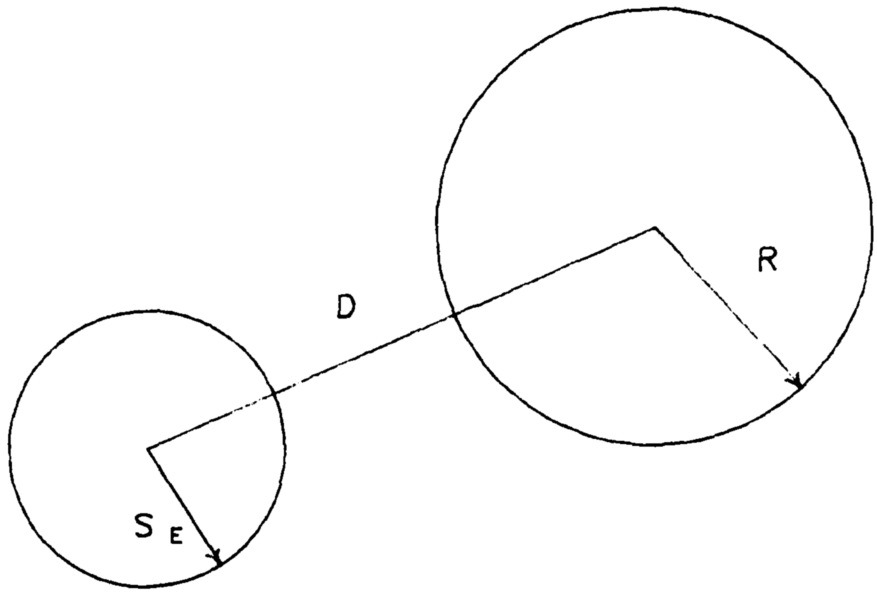


FIGURE A-1 - Geometry of CEP Expansion

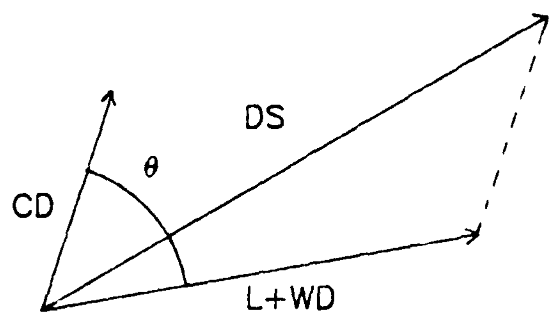


FIGURE A-2 - Vector Addition of Drift Components

Then $$DS = \sqrt{(CD)^2 + (L+WD)^2 - 2(CD)(L+WD)\cos(\pi - \theta)}$$
$$= \sqrt{(2)^2 + (1.5 + .76)^2 - 2\,(2)(1.5 + .76)\cos(2\pi/3)}$$
$$= 3.69$$

If the original CEP was 5.0 nm, and we assume that Sy = 3.0 nm, then a 4-hour drift period will result in

$$D = (369)(4) = 14.76$$

$$R = 1.1\sqrt{.3\,(14.76)^2 + 25 + 9} = 10.97 \text{ miles}$$

APPENDIX B

Historical wave height data are often presented in bar chart form, as in Reference B-1. These charts depict the relative frequency of occurrence of waves in a number of wave height "bins," for a given location and time of year. Comparison of these bar charts with plots of frequency functions of the binomial distribution suggest the following method of parameterizing a collection of realistic wave height distributions. Select an appropriate number of bins and compute the values of the binomial frequency function

$$P(k) = (\theta)^k \quad (1-\theta)^{n-k} \qquad , k = 0,1,\ldots,n-1,$$

for various values of the parameter θ ($\theta \in [0,1]$). Figure B-1 shows six such distributions each with 8 bins (n=7), and demonstrates the range of wave height distributions which can be simulated. In fact it is not difficult to find actual locations whose recorded wave height distributions are very close to those generated by this method.

The SAR model was run with a sequence of such distributions with the parameters ranging from 0.05 through 0.50 in increments of 0.05. The mean of the binomial distribution given above is $n\theta$, and completely characterizes the distribution. Since these distributions represent recorded significant (average 1/3 highest) wave heights, the term "mean significant wave height" was used to specify each distribution.

Reference:

B-1. Wind and Wave Summaries for Selected U.S. Coast Guard Operating Areas. Coast Guard R&D Center Report No. CG-D-11-83.

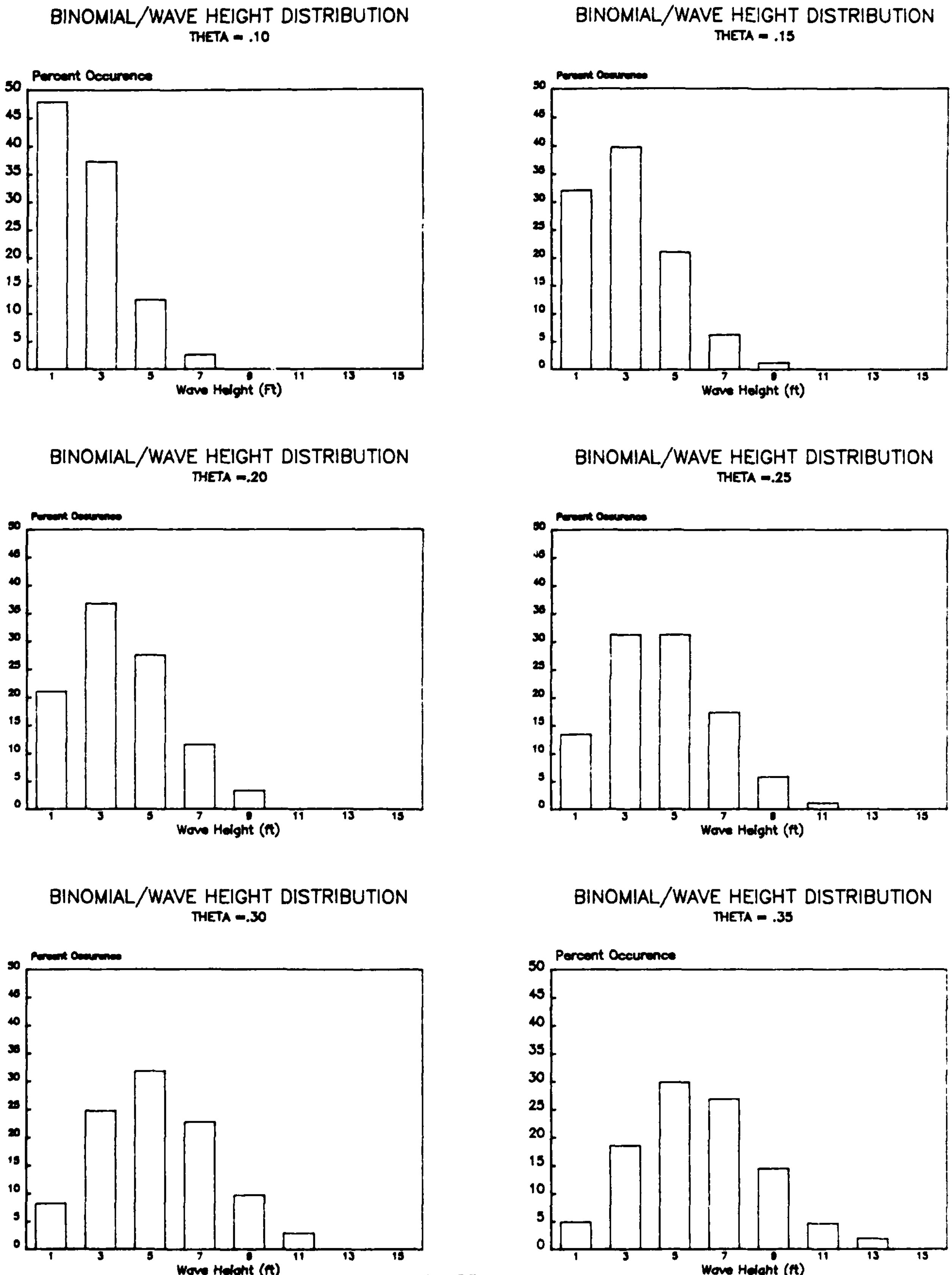

BINOMIAL/WAVE HEIGHT DISTRIBUTION
THETA = .10
Percent Occurence
Wave Height (Ft)
BINOMIAL/WAVE HEIGHT DISTRIBUTION
THETA = .15
Percent Occurence
Wave Height (ft)
BINOMIAL/WAVE HEIGHT DISTRIBUTION
THETA =.20
Percent Occurence
Wave Height (ft)
BINOMIAL/WAVE HEIGHT DISTRIBUTION
THETA =.25
Percent Occurence
Wave Height (ft)
BINOMIAL/WAVE HEIGHT DISTRIBUTION
THETA =.30
Percent Occurence
Wave Height (ft)
BINOMIAL/WAVE HEIGHT DISTRIBUTION
THETA = .35
Percent Occurence
Wave Height (ft)

FIGURE B-1

```
$ ty main.for
        PROGRAM MAIN
C
C
        COMMON/ARRAY/SEA(8,2),              !SEA STATE ARRAY
     1              PERCNT,                 !PERCENT TIME OVER SS 5
     2              SPEED(8),               !SPEED VS SEA STATE
     2              DUMMY1,                 !AVAILABLE
     3              DTOD(8,2),              !DISTANCE TO DATUM ARRAY
     3              DATUM,                  !MEAN DISTANCE TO DATUM
     4              UNDRWY(10,2),           !TIME TO UNDERWAY ARRAY DIMENSION
     4              UNDER,                  !MEAN TIME TO UNDERWAY
     5              XNOTFY(9,2),            !INCIDENT TO NOTIFY TIMES
     5              DELAY,                  !MEAN DELAY TIME BEFORE NOTIFICATION
     6              XINCID(24,2),           !INCIDENT TIME OF DAY ARRAY
     6              PEAK,                   !TIME OF PEAK CASELOAD
     7              SURVIV(0:13,2),         !SURVIVAL PROB. ARRAY
     7              EXPIRE,                 !TIME OF CERTAIN DEATH!!
     8              DWNDSK(2)               !DAWN/DUSK TIMES
        COMMON/GARBAGE/ISEED,               !RANDOM NUMBER SEED
     2              FTIME,                  !MEAN TIME TO FAILURE
     3              CURRENT,                !OCEAN CURRENT KTS.
     4              WIND,                   !WIND VELOCITY KTS.
     5              IANGLE,                 !ANGLE BETWEEN WIND & CURRENT
     6              IPEAK,                  !INTEGER VERSION OF PEAK
     7              ISCRN,                  !OUTPUT TO SCREEN INDICATOR
     8              MMAX                    !TOTAL NUMBER OF MONTE CARLO REPS

C
        CHARACTER*1 CHAR
        CHARACTER*24 FILE1,FILE2
C
C
        COMMON/FACTS/SIGMAX,                !SEARCH SPACE SIGMA
     2              SIGMAY,                 !SEARCH SPACE SIGMA
     3              WIDTH(2),               !DAY/NIGHT SEARCH WIDTHS
     4              SSPEED(2)               !DAY/NIGHT SEARCH SPEEDS
        COMMON/UNIT/ICRT,                   !WRITE UNIT NUMBER
     2             ITERM                    !READ UNIT NUMBER
        ICRT=6
        ITERM=6
C
C
C
        CALL SAR1
        CALL SAR2
        END
```

$ ty sar1.for

```
      SUBROUTINE SAR1
C
C
      COMMON/ARRAY/SEA(8,2),                !SEA STATE ARRAY
     1            PERCNT,                   !PERCENT TIME OVER SS 3
     2            SPEED(8),                 !SPEED VS SEA STATE
     2            DUMMY1,                   !AVAILABLE
     3            DTOD(8,2),                !DISTANCE TO DATUM ARRAY
     3            DATUM,                    !MEAN DISTANCE TO DATUM
     4            UNDRWY(10,2),             !TIME TO UNDERWAY ARRAY DIMENSION
     4            UNDER,                    !MEAN TIME TO UNDERWAY
     5            XNOTFY(9,2),              !INCIDENT TO NOTIFY TIMES
     5            DELAY,                    !MEAN DELAY TIME BEFORE NOTIFICATION
     6            XINCID(24,2),             !INCIDENT TIME OF DAY ARRAY
     6            PEAK,                     !TIME OF PEAK CASELOAD
     7            SURVIV(0:13,2),           !SURVIVAL PROB. ARRAY
     7            EXPIRE,                   !TIME OF CERTAIN DEATH!!
     8            DWNDSK(2)                 !DAWN/DUSK TIMES
      COMMON/GARBAGE/ISEED,                 !RANDOM NUMBER SEED
     2              FTIME,                  !MEAN TIME TO FAILURE
     3              CURRENT,                !OCEAN CURRENT KTS.
     4              WIND,                   !WIND VELOCITY KTS.
     5              IANGLE,                 !ANGLE BETWEEN WIND & CURRENT
     6              IPEAK,                  !INTEGER VERSION OF PEAK
     7              ISCRN,                  !OUTPUT TO SCREEN INDICATOR
     8              MMAX                    !TOTAL NUMBER OF MONTE CARLO REPS
C
      CHARACTER*1 CHAR
      CHARACTER*24 FILE1,FILE2
C
C
      COMMON/FACTS/SIGMAX,                  !SEARCH SPACE SIGMA
     2            SIGMAY,                   !SEARCH SPACE SIGMA
     2            CEP,                      !CIRC ERROR PROBABLE
     3            WIDTH(2),                 !DAY/NIGHT SEARCH WIDTHS
     4            SSPEED(2)                 !DAY/NIGHT SEARCH SPEEDS
      COMMON/UNIT/ICRT,                     !WRITE UNIT NUMBER
     2           ITERM                      !READ UNIT NUMBER
      ICRT=6
      ITERM=6
C
C
C
C     USER ENTERS DISTRIBUTION CHOICES
C
C
C
3600  WRITE(ICRT,*) CHOICES FOR SEA STATE ARE:
      WRITE(ICRT,*) A. MEAN SIG WAVE HEIGHT=3.6 FT
      WRITE(ICRT,*) B. MEAN SIG WAVE HEIGHT=5.0 FT
      WRITE(ICRT,*) C. MEAN SIG WAVE HEIGHT=8.2 FT
```

```
      WRITE(ICRT,*)'ENTER A, B, OR C'
      READ(ITERM,3601)CHAR
3601  FORMAT(A1)
      IF(CHAR.NE.'A'.AND.CHAR.NE.'B'.AND.CHAR.NE.'C')THEN
        WRITE(ITERM,*)'BAD CHOICE'
        GO TO 3600
      END IF
      IF(CHAR.EQ.'A')THEN
        OPEN(UNIT=2,NAME='STATE1',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'B')THEN
        OPEN(UNIT=2,NAME='STATE2',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'C')THEN
        OPEN(UNIT=2,NAME='STATE3',FORM='FORMATTED',TYPE='OLD')
      END IF
      READ(2,*)SEA,PERCNT
      CLOSE(UNIT=2)
      IPRCNT=INT(100.*PERCNT)
C
C
C     SPEED VS SEA STATE CHOICES
C
C
5800  WRITE(ICRT,*)'SPEED VS SEA STATE (I.E. SHIP TYPE) CHOICES ARE:'
      WRITE(ICRT,*)'A. HYDROFOIL'
      WRITE(ICRT,*)'B. PLANING HULL'
      WRITE(ICRT,*)'C. SWATH'
      WRITE(ICRT,*)'D. SES'
      WRITE(ICRT,*)'E. DISPLACEMENT'
      WRITE(ICRT,*)'E. 95 FOOT WPB'
      WRITE(ICRT,*)'ENTER A, B, C, D, E, OR F'
      READ(ITERM,3601)CHAR
      IF(CHAR.NE.'A'.AND.CHAR.NE.'B'.AND.CHAR.NE.'C'
     2   .AND. CHAR.NE.'D'.AND.CHAR.NE.'E'.AND.CHAR.NE.'F')THEN
        WRITE(ITERM,*)'BAD CHOICE'
        GO TO 5800
      END IF
      IF(CHAR.EQ.'A')THEN
        OPEN(UNIT=2,NAME='SPEED1',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'B')THEN
        OPEN(UNIT=2,NAME='SPEED2',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'C')THEN
        OPEN(UNIT=2,NAME='SPEED3',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'D')THEN
        OPEN(UNIT=2,NAME='SPEED4',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'E')THEN
        OPEN(UNIT=2,NAME='SPEED5',FORM='FORMATTED',TYPE='OLD')
      END IF
```

```
      IF(CHAR.EQ.'F')THEN
        OPEN(UNIT=2,NAME='SPEED6',FORM='FORMATTED',TYPE='OLD')
      END IF

      READ(2,*)SPEED,DUMMY1
      CLOSE(UNIT=2)
C
C
C     DISTANCE TO DATUM CHOICES
C
C
7700  WRITE(ICRT,*)'CHOICES FOR DISTANCE TO DATUM DISTRIBUTION ARE:
      WRITE(ICRT,*)'A. PEAKED AT 37.5 NM OFFSHORE'
      WRITE(ICRT,*)'B. PEAKED AT 57.5 NM OFFSHORE
      WRITE(ICRT,*)'C. PEAKED AT 77.5 NM OFFSHORE'
      WRITE(ICRT,*)'ENTER A, B, OR C
      READ(ITERM,3601)CHAR
      IF(CHAR.NE.'A'.AND.CHAR.NE.'B'.AND.CHAR.NE.'C')THEN
        WRITE(ITERM,*)'BAD CHOICE'
        GO TO 7700
      END IF
      IF(CHAR.EQ.'A')THEN
        OPEN(UNIT=2,NAME='DIST1',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'B')THEN
        OPEN(UNIT=2,NAME='DIST2',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'C')THEN
        OPEN(UNIT=2,NAME='DIST3',FORM='FORMATTED',TYPE='OLD')
      END IF
      READ(2,*)DTOD,DATUM
      CLOSE(UNIT=2)
C
C
C     TIME TO UNDERWAY CHOICES
C
C
9900  WRITE(ICRT,*)'CHOICES FOR TIME TO UNDERWAY DISTRIBUTION ARE:
      WRITE(ICRT,*)'A. IMMEDIATE'
      WRITE(ICRT,*)'B. 20% SPIKE AT 0 THEN TENT CENTERED AT 6 MIN.
      WRITE(ICRT,*)'C. UNIFORM ON 0 TO 12 MINUTES'
      WRITE(ICRT,*)'ENTER A, B, OR C'
      READ(ITERM,3601)CHAR
      IF(CHAR.NE.'A'.AND.CHAR.NE.'B'.AND.CHAR.NE.'C')THEN
        WRITE(ITERM,*)'BAD CHOICE'
        GO TO 9900
      END IF
      IF(CHAR.EQ.'A')THEN
        OPEN(UNIT=2,NAME='GETGO1',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'B')THEN
        OPEN(UNIT=2,NAME='GETGO2',FORM='FORMATTED',TYPE='OLD')
      END IF
```

```
      IF(CHAR.EQ.'C')THEN
        OPEN(UNIT=2,NAME='GETGO3',FORM='FORMATTED',TYPE='OLD')
      END IF
      READ(2,*)UNDRWY,UNDER
      CLOSE(UNIT=2)
C
C
C     TIME TO NOTIFICATION DISTRIBUTION
C
C
12100 WRITE(ICRT,*)'CHOICES FOR TIME TO NOTIFICATION DIST. ARE:'
      WRITE(ICRT,*)'A. IMMEDIATE'
      WRITE(ICRT,*)'B. UNIFORM ON 0 TO 1 HOUR'
      WRITE(ICRT,*)'C. UNIFORM ON 0-1 HR THEN RAMP DOWN TO 5 HRS'
      WRITE(ICRT,*)'ENTER A, B, OR C'
      READ(ITERM,3601)CHAR
      IF(CHAR.NE.'A'.AND.CHAR.NE.'B'.AND.CHAR.NE.'C')THEN
        WRITE(ITERM,*)'BAD CHOICE'
        GO TO 12100
      END IF
      IF(CHAR.EQ.'A')THEN
        OPEN(UNIT=2,NAME='NOTIF1',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'B')THEN
        OPEN(UNIT=2,NAME='NOTIF2',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'C')THEN
        OPEN(UNIT=2,NAME='NOTIF3',FORM='FORMATTED',TYPE='OLD')
      END IF
      READ(2,*)XNOTFY,DELAY
      CLOSE(UNIT=2)
C
C
C     INCIDENT TIME OF DAY DISTRIBUTION
C
C
14300 WRITE(ICRT,*)'CHOICES FOR INCIDENT TIME OF DAY DIST. ARE:'
      WRITE(ICRT,*)'A. UNIFORM OVER ENTIRE DAY'
      WRITE(ICRT,*)'B. BROAD PEAK AT 1600 HRS'
      WRITE(ICRT,*)'C. BROAD PEAK AT 2000 HRS'
      WRITE(ICRT,*)'ENTER A, B, OR C'
      READ(ITERM,3601)CHAR
      IF(CHAR.NE.'A'.AND.CHAR.NE.'B'.AND.CHAR.NE.'C')THEN
        WRITE(ITERM,*)'BAD CHOICE'
        GO TO 14300
      END IF
      IF(CHAR.EQ.'A')THEN
        OPEN(UNIT=2,NAME='INCTIME1',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'B')THEN
        OPEN(UNIT=2,NAME='INCTIME2',FORM='FORMATTED',TYPE='OLD')
      END IF
      IF(CHAR.EQ.'C')THEN
```

```
          OPEN(UNIT=2,NAME='INCTIME3',FORM='FORMATTED',TYPE='OLD')
        END IF
        READ(2,*)XINCID,PEAK
        CLOSE(UNIT=2)
C
C
C       SURVIVAL TIME DISTRIBUTION
C
C
16600   WRITE(ICRT,*)'CHOICES FOR SURVIVAL TIME DISTRIBUTION ARE:'
        WRITE(ICRT,*)'A. 10 HOUR MAX SURVIVAL TIME'
        WRITE(ICRT,*)'B. 20 HOUR MAX SURVIVAL TIME'
        WRITE(ICRT,*)'C. 30 HOUR MAX SURVIVAL TIME'
        WRITE(ICRT,*)'ENTER A, B, OR C'
        READ(ITERM,3601)CHAR
        IF(CHAR.NE.'A'.AND.CHAR.NE.'B'.AND.CHAR.NE.'C')THEN
          WRITE(ITERM,*)'BAD CHOICE'
          GO TO 16600
        END IF
        IF(CHAR.EQ.'A')THEN
          OPEN(UNIT=2,NAME='SURV1',FORM='FORMATTED',TYPE='OLD')
        END IF
        IF(CHAR.EQ.'B')THEN
          OPEN(UNIT=2,NAME='SURV2',FORM='FORMATTED',TYPE='OLD')
        END IF
        IF(CHAR.EQ.'C')THEN
          OPEN(UNIT=2,NAME='SURV3',FORM='FORMATTED',TYPE='OLD')
        END IF
        READ(2,*)SURVIV,EXPIRE
        CLOSE(UNIT=2)
C
C
C       ALL THE OTHER GARBAGE
C
C
80      WRITE(ICRT,*)'ENTER TIME AT DAWN (24 HOUR CLOCK)'
        READ(ITERM,*,ERR=82)DWNDSK(1)
        IDAWN=INT(DWNDSK(1))
        IF(DWNDSK(1).LT.0.0.OR.DWNDSK(1).GT.2400.0)GO TO 82
        DD=(DWNDSK(1)-(INT(DWNDSK(1)/100.)*100.))/60.
        DWNDSK(1)=INT(DWNDSK(1)/100.)+DD
        GO TO 85
82      WRITE(ICRT,*)' HOURS ENTERED ARE NOT WITHIN RANGE OF 0000-2400.'
        GO TO 80
85      WRITE(ICRT,*)'ENTER TIME AT DUSK (24 HOUR CLOCK)'
        READ(ITERM,*,ERR=86)DWNDSK(2)
        IDUSK=INT(DWNDSK(2))
        IF(DWNDSK(2).LT.0.0.OR.DWNDSK(2).GT.2400.0)GO TO 86
        DD=(DWNDSK(2)-(INT(DWNDSK(2)/100.)*100.))/60.
        DWNDSK(2)=INT(DWNDSK(2)/100.)+DD
        GO TO 87
86      WRITE(ICRT,*)' HOURS ENTERED ARE NOT WITHIN RANGE OF 0000-2400.
        GO TO 85
```

```
87      CONTINUE
C*****************************************************************************
        CEP=.1*DATUM
C*******************************************************************************
90      WRITE(ICRT,*)'ENTER DAYTIME SEARCH WIDTH (MILES)'
        READ(ITERM,*,ERR=92) WIDTH(1)
        GO TO 94
92      WRITE(ICRT,*)'UNSATISFACTORY RESPONSE; TRY AGAIN'
        GO TO 90
94      CONTINUE
95      WRITE(ICRT,*)'ENTER  NIGHT SEARCH WIDTH (MILES)'
        READ(ITERM,*,ERR=97) WIDTH(2)
        GO TO 99
97      WRITE(ICRT,*)'UNSATISFACTORY RESPONSE; TRY AGAIN'
        GO TO 95
99      CONTINUE
C******************************************************************************
100     WRITE(ICRT,*)'ENTER A RANDOM NUMBER GENERATOR SEED (INTEGER 1-1000)'
        READ(ITERM,*,ERR=102) ISEED
        GO TO 104
102     WRITE(ICRT,*)'UNSATISFACTORY RESPONSE; TRY AGAIN'
        GO TO 100
104     CONTINUE
C*****************************************************************************
105     WRITE(ICRT,*)'ENTER MEAN TIME BETWEEN FAILURE'
        READ(ITERM,*,ERR=1051) FTIME
        GO TO 1052
1051    WRITE(ICRT,*)'UNSAT; TRY AGAIN'
        GO TO 105
1052    CONTINUE
C*****************************************************************************
C
107     WRITE(ICRT,*)'ENTER CURRENT (KTS)'
        READ(ITERM,*,ERR=1071)CURENT
        GO TO 1072
1071    WRITE(ICRT,*)'UNSAT'
        GO TO 107
1072    CONTINUE
C
C
108     WRITE(ICRT,*)'ENTER WIND SPEED (KTS)
        READ(ITERM,*,ERR=1081)WIND
        GO TO 1082
1081    WRITE(ICRT,*)'UNSAT'
        GO TO 108
1082    CONTINUE
C
C
109     WRITE(ICRT,*)'ENTER ANGLE BETWEEN WIND AND CURRENT (DEG)
        READ(ITERM,*,ERR=1091)IANGLE
        GO TO 1092
1091    WRITE(ICRT,*)'UNSAT'
        GO TO 109
```

```
1092    CONTINUE
C
C
        IPEAK=INT(PEAK)
C***************************************************************************
C106     WRITE(ICRT,*)'ENTER NUMBER OF SAMPLES PER REPLICATION'
C        READ(ITERM,*,ERR=1061)ISMPLS
C        GO TO 1062
C1061    WRITE(ICRT,*)'UNSAT; TRY AGAIN'
C        GO TO 106
C1062    CONTINUE
110     WRITE(ICRT,*)'ENTER NUMBER OF REPLICATIONS'
        READ(ITERM,*,ERR=1101)IREPS
        GO TO 1102
1101    WRITE(ICRT,*)'UNSAT; TRY AGAIN'
        GO TO 110
1102    CONTINUE
        MMAX=IREPS
C***************************************************************************
        WRITE(ICRT,*)'ENTER NAME OF  FILE TO HOLD USER CHOICES'
        READ(ITERM,111)FILE1
111     FORMAT(A24)
        OPEN(NAME=FILE1,TYPE='NEW',FORM='FORMATTED',UNIT=3)
        WRITE(ICRT,*)'ENTER NAME OF FILE FOR PROGRAM OUTPUT'
        READ(ITERM,111)FILE2
C       OPEN(NAME=FILE2,TYPE='NEW',FORM='FORMATTED',UNIT=2)
        OPEN(UNIT=4,NAME='IALIVE',FORM='FORMATTED',TYPE='NEW')
C       WRITE(2,*)ISMPLS,IREPS
        WRITE(3,*)SPEED(1),SPEED(3),UNDER
        WRITE(3,*)FTIME,WIDTH(1),WIDTH(2)
        WRITE(3,*)DELAY,IPEAK,EXPIRE
        WRITE(3,*)DATUM,CEP,CURENT,WIND,IANGLE
        WRITE(3,*)IPRCNT,IDAWN,IDUSK
        WRITE(3,*)ISMPLS,IREPS
        WRITE(4,*)MMAX
115     WRITE(ICRT,*)'DO YOU WANT OUTPUT ON SCREEN? (Y/N)'
        READ(ITERM,3601)CHAR
        IF(CHAR.NE.'Y'.AND.CHAR.NE.'N')THEN
        WRITE(ITERM,*)'HUH?'
        GO TO 115
        END IF
        IF(CHAR.EQ.'Y')THEN
        ISCRN=1
        END IF
        IF(CHAR.EQ.'N')THEN
        ISCRN=0
        END IF
        IF(ISCRN .EQ. 1) THEN
          WRITE(ICRT,400)
        END IF
  400   FORMAT('1')
        RETURN
        END
```

```
$ ty sar2.for

        SUBROUTINE SAR2
C
C
        COMMON/ARRAY/SEA(8,2),            !SEA STATE ARRAY
     1               PERCNT,              !PERCENT TIME OVER 5 FEET
     2               SPEED(8),            !SPEED VS SEA STATE
     2               DUMMY1,              !AVAILABLE
     3               DTOD(8,2),           !DISTANCE TO DATUM ARRAY
     3               DATUM,               !MEAN DISTANCE TO DATUM
     4               UNDRWY(10,2),        !TIME TO UNDERWAY ARRAY DIMENSION
     4               UNDER,               !MEAN TIME TO UNDERWAY
     5               XNOTFY(9,2),         !INCIDENT TO NOTIFY TIMES
     5               DELAY,               !MEAN DELAY TIME BEFORE NOTIFICATION
     6               XINCID(24,2),        !INCIDENT TIME OF DAY ARRAY
     6               PEAK,                !TIME OF PEAK CASELOAD
     7               SURVIV(0:13,2),      !SURVIVAL PROB. ARRAY
     7               EXPIRE,              !TIME OF CERTAIN DEATH!!
     8               DWNDSK(2)            !DAWN/DUSK TIMES
        COMMON/GARBAGE/ISEED,             !RANDOM NUMBER SEED
     2                FTIME,              !MEAN TIME TO FAILURE
     3                CURRENT,            !OCEAN CURRENT KTS.
     4                WIND,               !WIND VELOCITY KTS.
     5                IANGLE,             !ANGLE BETWEEN WIND & CURRENT
     6                IPEAK,              !INTEGER VERSION OF PEAK
     7                ISCRN,              !OUTPUT TO SCREEN INDICATOR
     8                MMAX                !TOTAL NUMBER OF MONTE CARLO REPS

C
        CHARACTER*1 CHAR
        CHARACTER*24 FILE1,FILE2
C
C
        COMMON/INFO/SSTATE,               !SAMPLE SEA STATE
     2              V,                    !CORRESP. SAMPLE SPEED
     3              DIST,                 !SAMPLE DISTANCE TO DATUM
     4              TTRANS,               !CORRESP. TRANSIT TIME
     5              TUNDER,               !SAMPLE UNDERWAY DELAY TIME
     6              TNOTFY,               !SAMPLE NOTIFICATION TIME
     7              TCINC,                !SAMPLE CLOCK TIME OF INCIDENT
     8              TDATUM,               !CORRESP. TIME TO DATUM
     9              TCDATM,               !CLOCK TIME TO DATUM
     8              TEXPIR,               !TIME TO DEATH W/ PROB 1
     7              IUP,                  !SHIP UP ON SCENE: 1=YES
     6              ISERCH,               !SEARCH REQ'D: 1=YES
     6              TFIND,                !SAMPLE TIME TO FIND
     6              ICESS,                !SUCCESSFUL SEARCH: 1=YES
     5              TSCENE,               !RESULTANT TIME TO SCENE
     4              TCCENE,               !CLOCK TIME ON SCENE
     4              PALIVE,               !RESULTANT PROB OF SURVIVAL
```

```
     3              IALIVE,                  !SURVIVAL INDICATOR: 1=ALIVE
     2              IQUIT                    !1=SEARCH BROKEN OFF UNSUCCESSFULLY
      COMMON/FACTS/SIGMAX,                   !SEARCH SPACE SIGMA
     2              SIGMAY,                  !SEARCH SPACE SIGMA
     2              CEP,                     !CIRC ERROR PROBABLE
     3              WIDTH(2),                !DAY/NIGHT SEARCH WIDTHS
     4              SSPEED(2)                !DAY/NIGHT SEARCH SPEEDS
      COMMON/UNIT/ICRT,                      !WRITE UNIT NUMBER
     2              ITERM                    !READ UNIT NUMBER
C************************************************************************
C
      TEXPIR=SURVIV(13,1)
      ANGLE=FLOAT(IANGLE)
      EEWAY=.05*WIND
      WDRIFT=.033*WIND-.23
      IF(WDRIFT.LT.0.)WDRIFT=0.
      DSQ=(EEWAY+WDRIFT)**2+CURENT**2
      DSQ=DSQ-2*CURENT*(EEWAY+WDRIFT)*COS(3.14159-ANGLE)
      IF(DSQ.LE.0)THEN
      DSQ=0
      GO TO 26
      END IF
      DRIFT=SQRT(DSQ)
 26   CONTINUE
      DRIFT=.5*DRIFT*TEXPIR
      R=1.1*SQRT(.3*DRIFT**2+CEP**3+9)
      SIGMAX=.849322*R
      SIGMAY=SIGMAX

C
C

C
C     START THE MAIN REPLICATION LOOP
C     LOOP INDEX IS 'MAIN'
C
C
C
      MAIN=1
 999  CONTINUE
C     WRITE(6,*)'MAIN= ',MAIN
      IQUIT=0
      SSTATE=SAMPLE(SEA,8,ISEED)
C     WRITE(6,*)'WAVE HEIGHT= ',SSTATE
      V=SPEED(SSTATE)
C     WRITE(6,*)'V= ',V
      SSPEED(1)=V
      SSPEED(2)=V
      DIST=SAMPLE(DTOD,8,ISEED)
C     WRITE(6,*)'DIST= ',DIST
      TTRANS=DIST/V
C     WRITE(6,*)'TTRANS= ',TTRANS
      TUNDER=SAMPLE(UNDRWY,10,ISEED)
```

```
C       WRITE(6,*)'TUNDER=',TUNDER
        TNOTFY=SAMPLE(XNOTFY,9,ISEED)
C       WRITE(6,*)'TNOTFY= .TNOTFY
        TCINC=SAMPLE(XINCID,24,ISEED)
C       WRITE(6,*)'TCINC=',TCINC
        TDATUM=TTRANS+TUNDER+TNOTFY
        TCDATM=TCINC+TDATUM

C       WRITE(6,*)'TEXPIR=',TEXPIR
        TMAX=TEXPIR-TDATUM
C       WRITE(6,*)'TMAX=',TMAX
C
C
C
C
C       DETERMINE TOTAL SEARCH TIME
C
C
        TNEW=AMOD(TCDATM,24.)
        IF(TNEW .LT. DWNDSK(2) .AND.
     2     TNEW .GT. DWNDSK(1)) THEN                !LIGHT AT DATUM
          IF(DWNDSK(2)-TNEW .GT. TMAX) THEN                 !DEAD BEFORE DUSK
            TSERCH=DWNDSK(2)-TNEW
          ELSE
            TSERCH=DWNDSK(2)-TNEW+24.               !SEARCH EXTRA DAY
          END IF
        ELSE                                                !DARK AT DATUM
          IF((24.-(TNEW-DWNDSK(2))) .GT. TMAX) THEN  !DEAD BFOR NEXT DSK
            TSERCH=24.-(TNEW-DWNDSK(2))
          ELSE                                              !DEAD AFTER NEXT DUSK
            TSERCH=48.-(TNEW-DWNDSK(2))
          END IF
        END IF
C       WRITE(6,*)'TSERCH=',TSERCH
C
C
C
          ICESS=1
          CALL SEARCH(TNEW,TSERCH,DWNDSK,ISEED,TFIND)
C       WRITE(6,*)'BACK IN SAR,TFIND=',TFIND
          IF(TFIND .EQ. -1.0)THEN
C           WRITE(6,*)'DID NOT FIND'
            ISERCH=1
            TFIND=TSERCH
            ICESS=0
            TSCENE=999.
            TCCENE=999.
            UPTEST=TDATUM+TSERCH
            PALIVE=0.
            IALIVE=0
            IQUIT=1
            EVEN=RAN(ISEED)
            GO TO 2000
```

```
      END IF
      IF(TFIND .LT. .25) THEN
        ISERCH=0
      ELSE
        ISERCH=1
      END IF
      TSCENE=TDATUM+TFIND
      TCCENE=TCDATM+TFIND
      UPTEST=TSCENE
      J=1
 1000 IF(TSCENE .LT. SURVIV(J,1)) THEN
        PALIVE=SURVIV(J-1,2)
      ELSE
        J=J+1
        IF(J .GT. 13) THEN
C         WRITE(ICRT,*)'TIME TO FIND WAS TOO LONG:TFIND=',TFIND
          PALIVE=0.
          GO TO 1001
        END IF
      GO TO 1000
 1001 CONTINUE
      END IF
C     WRITE(6,*)'PALIVE=',PALIVE
      TEST1=RAN(ISEED)
      IF(TEST1 .LT. PALIVE) THEN
        IALIVE=1
      ELSE
        IALIVE=0
      END IF
 2000 CONTINUE
      RLAM=1./FTIME
      REL=EXP(-RLAM*UPTEST)
      TEST=RAN(ISEED)
      IF(TEST .GT. REL) THEN
        IUP=0
      ELSE
        IUP=1
      END IF
      IF(ISCRN .EQ. 1) THEN
        CALL SCREEN(MAIN)
      END IF
      CALL FILE
      MAIN=MAIN+1
      IF(MAIN .LE. MMAX) THEN
        GO TO 999
      ELSE
        WRITE(ICRT,*)'FINISHED
      END IF
      CLOSE(UNIT=2)
      RETURN
      END
```

```
C       SUBROUTINE TO WRITE SAR MOE OUTPUTS TO THE SCREEN
C       MAIN IS THE REPLICATION LOOP COUNTER IN PROGRAM RWSAR
C       THE HEADINGS ARE REPEATED EVERY 20 LINES
C
C
C
        SUBROUTINE SCREEN(MAIN)
        COMMON/INFO/SSTATE,V,DIST,TTRANS,TUNDER,
     2             TNOTFY,TCINC,TDATUM,TCDATM,
     3             TEXPIR,IUP,ISERCH,TFIND,ICESS,TSCENE,
     4             TCCENE,PALIVE,IALIVE
        COMMON/UNIT/ICRT,ITERM
C
C
C
        IF(MOD(MAIN,20) .EQ. 1) THEN
          WRITE(ICRT,*)'|--------CASE DATA---------| |-------OPERATIO
     2NS--------| |---PERFORMANCE---|'
          WRITE(ICRT,*)'CLOCK TIME  DISTANCE TIME TO TIME TO  TRANSIT
     2TIME SPENT SUCCESSFUL  PROB OF'
          WRITE(ICRT,*)'OF INCIDENT TO DATUM NOTIFY  UNDERWAY  TIME

     2  SEARCHING  SEARCH    SURVIVAL'
        END IF
C
C
C
        WRITE(ICRT,100)TCINC,DIST,TNOTFY,TUNDER,TTRANS,
     2                 TFIND,ICESS,PALIVE
 100    FORMAT(3X,F6.2,4X,F6.2,3X,F6.2,2X,F6.2,3X,F6.2,4X,F6.2,3X,I6,
     2         4X,F6.2)
        RETURN
        END




        SUBROUTINE SEARCH(TD,              !TIME OF DAY AT DATUM
     2                    TS,              !TOTAL ALLOWABLE SEARCH TIME
     3                    TIME,            !DAWN/DUSK TIMES (24 HR CLOCK)
     4                    ISEED,           !RANDOM NUMBER SEED
     5                    TTF)             !TIME TO FIND (RETURNED)
        DIMENSION TPOD(0:5),               !TIMES OF SUCC. PHASES OF SEARCH
     3            POD(0:5),                !POD AFTER SUCC. PHASES
     4            TT(2),                   !LENGTH OF DAY/NIGHT
     5            LIGHT(5),                !DAY=1,NIGHT=2 INDICATOR
     6            DTIME(6,2),              !START/STOP TIMES FOR DENSE(*),
     7            TIME(2)                  !DAWN/DUSK TIMES (24 HR CLOCK)
C       WRITE(6,*)'NOW IN SUBROUTINE SEARCH'
```

```
C       WRITE(6,*)'TD=',TD,'TS=',TS
C
C
C
C       IF TIME AT DATUM IS DURING DAYLIGHT, ISTART=1
C
C
C
        IF(TD .LT. TIME(2) .AND. TD .GT. TIME(1))THEN
          ISTART=1
        ELSE
          ISTART=2
        END IF
C       WRITE(6,*)'ISTART=',ISTART
C
C
C
        TPOD(0)=0.                          !FOR LOOPING CONVIENIENCE
        I=MOD(ISTART,2)+1                   !INITIALIZE DAY/NIGHT COUNTER
        J=0                                 !INITIALIZE TPOD SUBSCRIPT
        T=TIME(I)-TD                        !TIME REMAINING IN DAY/NIGHT
        IF(T .LT. 0.) THEN
          T=T+24.
        END IF
        TT(1)=TIME(2)-TIME(1)               !LENGTH OF DAY
        TT(2)=24.-TIME(2)+TIME(1)           !LENGTH OF NIGHT
C       WRITE(6,*)'LENGTH OF DAY/NIGHT=',TT(1),TT(2)
C
C
C
21      CONTINUE
        IF(T .GE. TS) GO TO 22
        J=J+1                               !INCREMENT TPOD SUBSCRIPT
        TPOD(J)=T                           !SET TPOD
        T=T+TT(I)                           !INCR. T BY NEXT DAY/NIGHT LENGTH
        I=MOD(I,2)+1                        !TOGGLE DAY/NIGHT COUNTER
        LIGHT(J)=I                          !SET DAY/NIGHT INDICATOR
C       WRITE(6,*)'J=',J
C       WRITE(6,*)'TPOD',J,'=',TPOD(J)
C       WRITE(6,*)'NEXT T=',T
C       WRITE(6,*)'NEW DAY/NIGHT INDICATOR=',I
        GO TO 21
22      CONTINUE
C
C
C
        J=J+1
        I=MOD(I,2)+1
        LIGHT(J)=I
        TPOD(J)=TS                          !FINAL TIME IS TOT. ALLOW. TIME
C       WRITE(6,*)'FINAL TIME =',TS,'FINAL DAY/NIGHT=',I
C
C
```

```
C
      POD(0)=0
      DTIME(1,1)=TPOD(0)                   !FIRST DENSE_TIMES ARE EASY
      DTIME(1,2)=TPOD(1)
C
C
C
      DO 100 I=1,J
      IF(I .EQ. 1) GO TO 150
      DTIME(I,1)=
     2     CINV(LIGHT(I),POD(I-1),DTIME(I-1,2))
      DTIME(I,2)=
     2     DTIME(I,1)+TPOD(I)-TPOD(I-1)
  150 CONTINUE
      POD(I)=POD(I-1)+
     2       CUMUL(LIGHT(I),DTIME(I,2))-
     3       CUMUL(LIGHT(I),DTIME(I,1))
C     WRITE(6,*)'I=',I
C     WRITE(6,*)'DTIME(I,1)=',DTIME(I,1)
C     WRITE(6,*)'DTIME(I,2)=',DTIME(I,2)
C     WRITE(6,*)'POD(I)=',POD(I)
  100 CONTINUE
C
C
C
      U=RAN(ISEED)
      IF (U .GT. POD(J)) THEN
        TTF=-1.
        RETURN
      ELSE
        I=1
102     CONTINUE
        IF(POD(I) .GT. U) GO TO 103
        I=I+1
        GO TO 102
103     CONTINUE
      TTF=TPOD(I-1)+CINV(LIGHT(I),U,DTIME(I,2))-DTIME(I,1)
      END IF
C
C
C
      RETURN
      END




C     FUNCTION TO COMPUTE THE CUMULATIVE POD AT A GIVEN TIME.
C     THE POD FUNCTION IS THAT GIVEN BY KOOPMAN FOR EXPONENTIAL
C     SENSOR CAPABILITY AND OPTIMAL ALLOCATION OF SEARCH EFFORT.
C
C
```

```
C
      FUNCTION CUMUL(I,TIME)           !I=1 MEANS DAY;=2MEANS NIGHT
      COMMON/FACTS/SIGMAX,             !SEARCH SPACE SIGMA (X)
     2            SIGMAY,              !SEARCH SPACE SIGMA (Y)
     2            CEP,                 !CIRC ERROR PROBABLE
     3            WIDTH(2),            !DAY/NIGHT SEARCH WIDTHS
     4            SPEED(2)             !DAY/NIGHT SEARCH SPEEDS
C
C
C
      PI=3.14159
      C=WIDTH(I)*SPEED(I)/(SIGMAX*SIGMAY*PI)
      ARG=SQRT(C*TIME)
      CUMUL=1.-(1.+ARG)*(EXP(-ARG))
      RETURN
      END
C
C
C
C     FUNCTION TO COMPUTE THE INVERSE OF THE SPLICED CUMULATIVE
C     POD OF THE SEARCH. AS THE POD FUNCTION IS TRANCENDENTAL,
C     AN ITERATIVE TECHNIQUE IS USED.
C     I=DAY/NIGHT INDICATOR;1=DAY,2=NIGHT
C     POD=CUMULATIVE POD ON DISTRIBUTION CUMUL(I)
C     TSTART=STARTING TIME FOR ITERATION
C
C
C
      FUNCTION CINV(I,POD,TSTART)
C
C
C
      COMMON/FACTS/SIGMAX,SIGMAY,CEP,WIDTH(2),SPEED(2)
      F(T)=1.-POD-(1.+SQRT(C*T))*EXP(-SQRT(C*T))
C
C
C
      PI=3.14159
      C=WIDTH(I)*SPEED(I)/(SIGMAX*SIGMAY*PI)
      T=TSTART
      DELTAT=T/2.
      ILESS=0
      IGREAT=0
   10 CONTINUE
      IF(ILESS .EQ. 1 .AND. IGREAT .EQ. 1) THEN
        ILESS=0
        IGREAT=0
        DELTAT=DELTAT/2.
      END IF
C
C
      IF(F(T) .GT. .001) THEN
        T=T-DELTAT
```

```
      IGREAT=1
      GO TO 10
    END IF
C
C
    IF(F(T) .LT. -.001) THEN
      T=T+DELTAT
      ILESS=1
      GO TO 10
    END IF
C
C
    CINV=T
C
C
    RETURN
    END
C
C
C
C   FUNCTION TO COMPUTE THE EXPONENTIAL POD FUNCTION.
C
C
C
    FUNCTION DENSE(I,TIME)
C
C
C
    COMMON/FACTS/SIGMAX,SIGMAY,CEP,WIDTH(2),SPEED(2)
C
C
C
    PI=3.14159
    C=WIDTH(I)*SPEED(I)/(SIGMAX*SIGMAY*PI)
    ARG=SQRT(C*TIME)
    DENSE=C*EXP(-ARG)/2.
    RETURN
    END
C
C
C
C   FUNCTION TO COMPUTE THE INVERSE OF THE EXPONENTIAL
C   POD FUNCTION.
C   X=DENSITY VALUE (I.E. THE ARGUMENT OF THE INVERSE FUNCTION)
C
C
C
    FUNCTION DINV(I,X)
C
C
C
    COMMON/FACTS/SIGMAX,SIGMAY,CEP,WIDTH(2),SPEED(2)
C
```

```
C
C
      PI=3.14159
      C=WIDTH(I)*SPEED(I)/(SIGMAX*SIGMAY*PI)
      ARG=2.*X/C
      DINV=(LOG(ARG))**2/C
      RETURN
      END


C     FUNCTION SUBPROGRAM TO SAMPLE FROM A DISCRETE
C     DISTRIBUTION.
C
C
C
      FUNCTION SAMPLE(DIST,           !ARRAY CONTAINING FREQ FUNCTION
     2                J,              !LENGTH OF ARRAY
     3                ISEED)          !SEED FOR RANDOM NUMBER GEN
C
C
      DIMENSION DIST(J,2)
      COMMON/UNIT/ICRT,ITERM
C
C
      Y=RAN(ISEED)
      SUM=0.
      I=1
 100  CONTINUE
      SUM=SUM+DIST(I,2)
      IF(SUM .GE. Y) THEN
        SAMPLE=DIST(I,1)
        RETURN
      END IF
      I=I+1
      IF(I .GT. J) THEN
        WRITE(ICRT,*) 'ERROR IN SAMPLE'
      ELSE
        GO TO 100
      END IF
      END


$ ty binom.for

      OPEN(UNIT=4,NAME='IALIVE',FORM='FORMATTED',TYPE='OLD')
      READ(4,*)MMAX
      ISUM=0
      ISUM2=0
      DO 100 I=1,MMAX
      READ(4,*)IPART,IQUIT
      ISUM=ISUM+IPART
```

```
      ISUM2=ISUM2+IQUIT
100   CONTINUE
      FSUM=FLOAT(ISUM)
      FMAX=FLOAT(MMAX)
      FSUM2=FLOAT(ISUM2)
      FRACTION=FSUM/FMAX
      FRACTION2=FSUM2/FMAX
      WRITE(6,*)'# OF SAMPLES =',MMAX
      WRITE(6,*)'FRACTION FOUND ALIVE =',FRACTION
      WRITE(6,*)'FRACTION PRESUMED DEAD=',FRACTION2
      ALF=1.96
      ROOT=SQRT(FSUM*(FMAX-FSUM)/FMAX+ALF**2/4)
      TERM1=ALF*ROOT
      TERM2=FSUM+ALF**2/2
      TERM3=FMAX+ALF**2
      BLOWER=(TERM2-TERM1)/TERM3
      BUPPER=(TERM2+TERM1)/TERM3
      WRITE(6,*)'LOWER BOUND OF 95% CONFIDENCE INTERVAL =',BLOWER
      WRITE(6,*)'UPPER BOUND OF 95% CONFIDENCE INTERVAL =',BUPPER
      END

$ lo

  ROEHRIG      logged out at 23-APR-1985 15:37:
Remote disconnect
```

END
DTIC
7-86